Do not edit
How to change the design

Please fill in the survey

The Slido app must be installed on every computer you're presenting from

slido

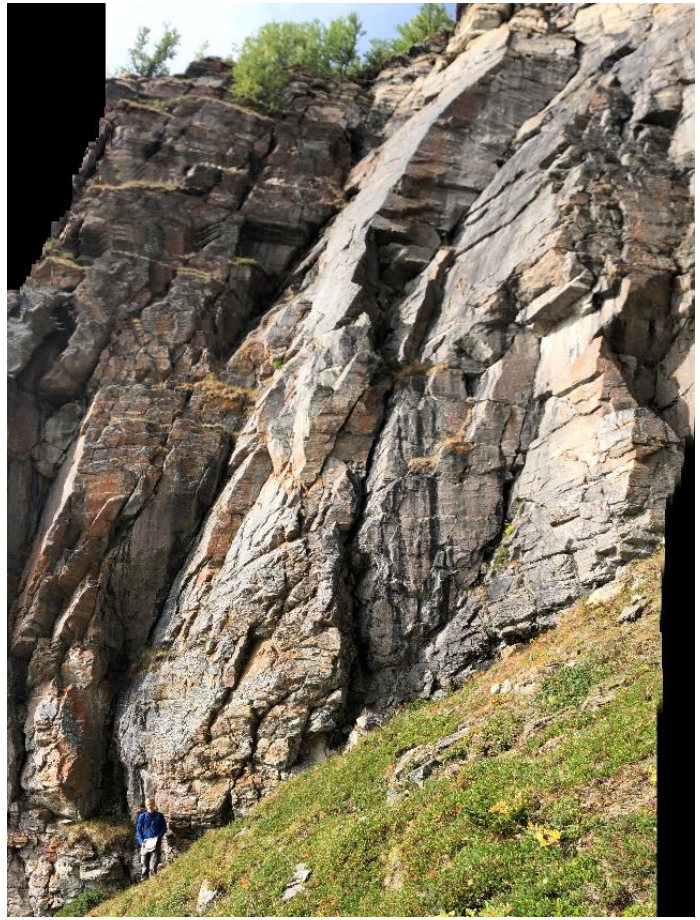
UiT The Arctic University of Norway

Structure in a rock mass

Louise Vick

Content

- Defining structure in rock
- Assessing and characterizing rock mass with structure
- Assessing the strength of jointed/structured rock mass (a brief introduction)
- Case study: St Francis Dam



Learning outcomes

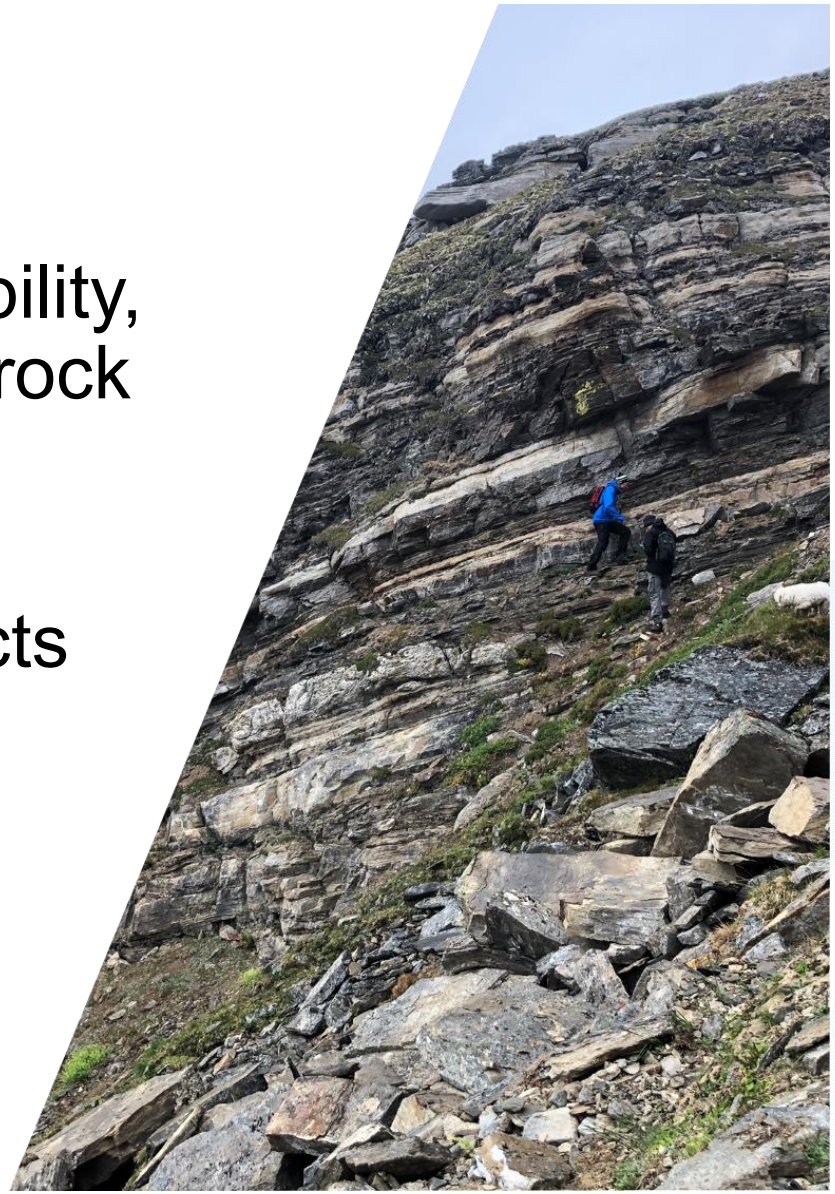
Understand the role structure plays in the strength of a rock mass

Define different structure types

Knowledge of working systems to classify a rock mass and their limitations

Structure in rock

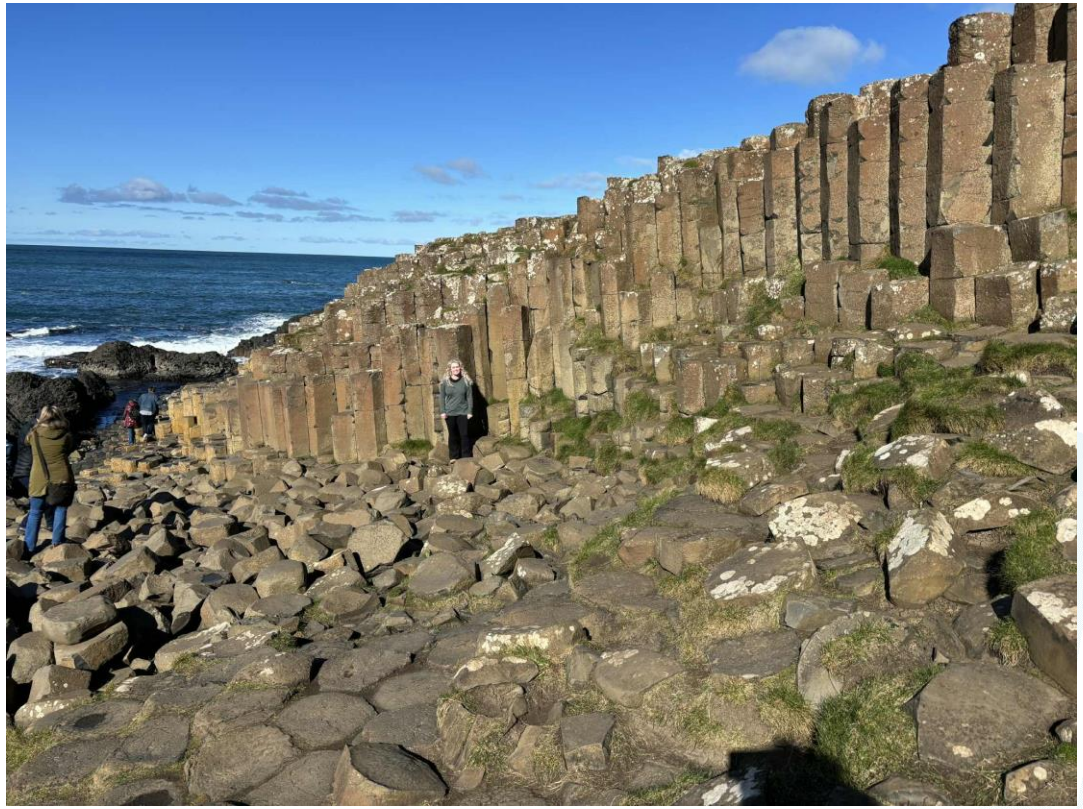
- Significantly influences the strength, stability, and deformational characteristics of the rock mass
- Their characterisation essential for geotechnical and civil engineering projects



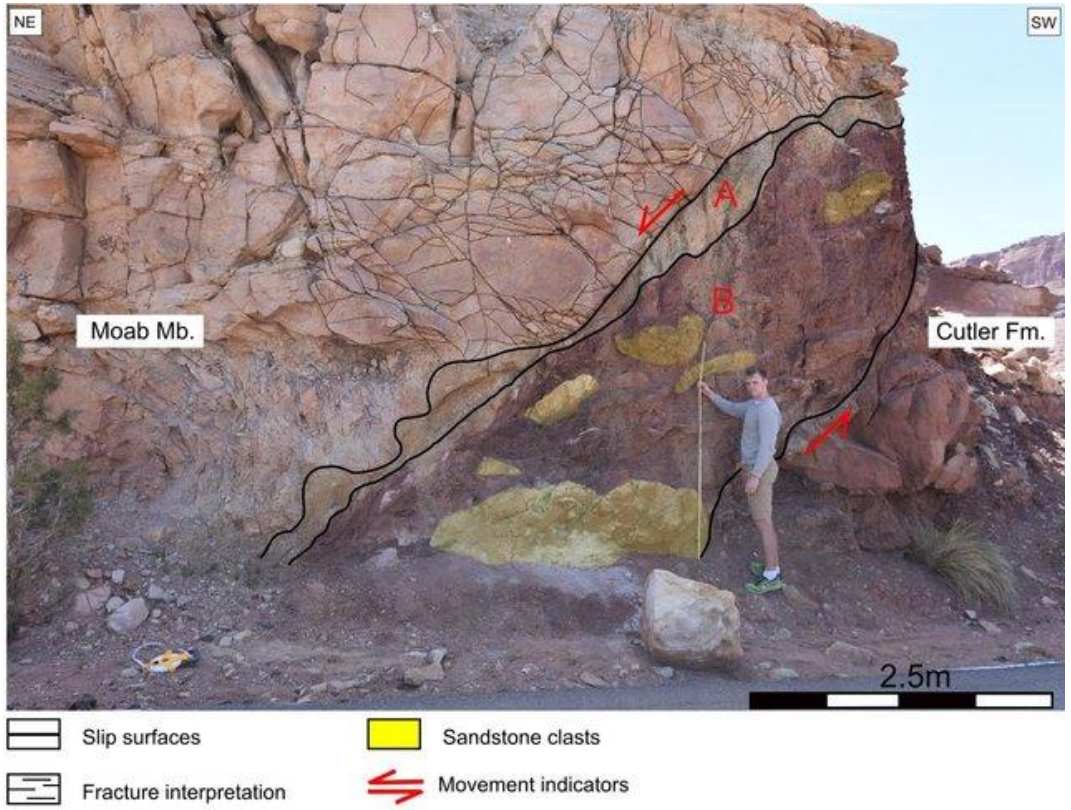
Typical structures in this region

- Joints
- Faults and shear zones
- Foliation
- Bedding planes

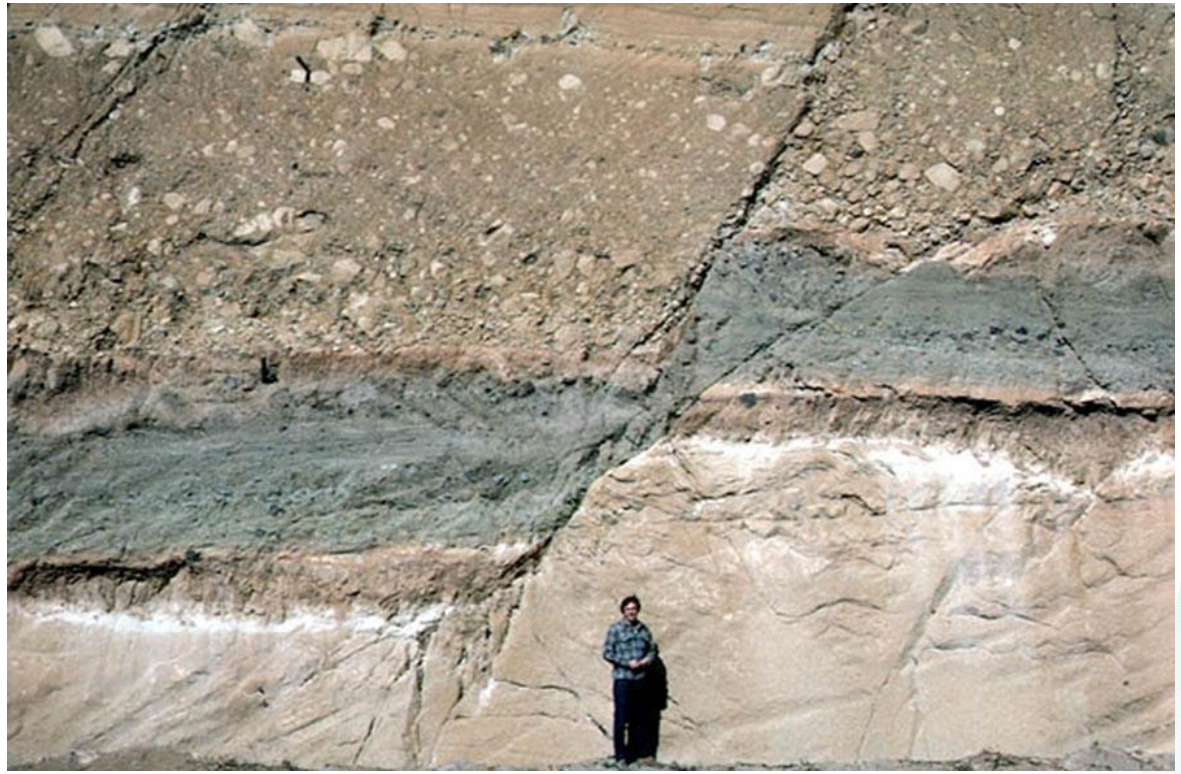
China, Cao et al 2016



N Ireland



Utah, Johannessen, 2017

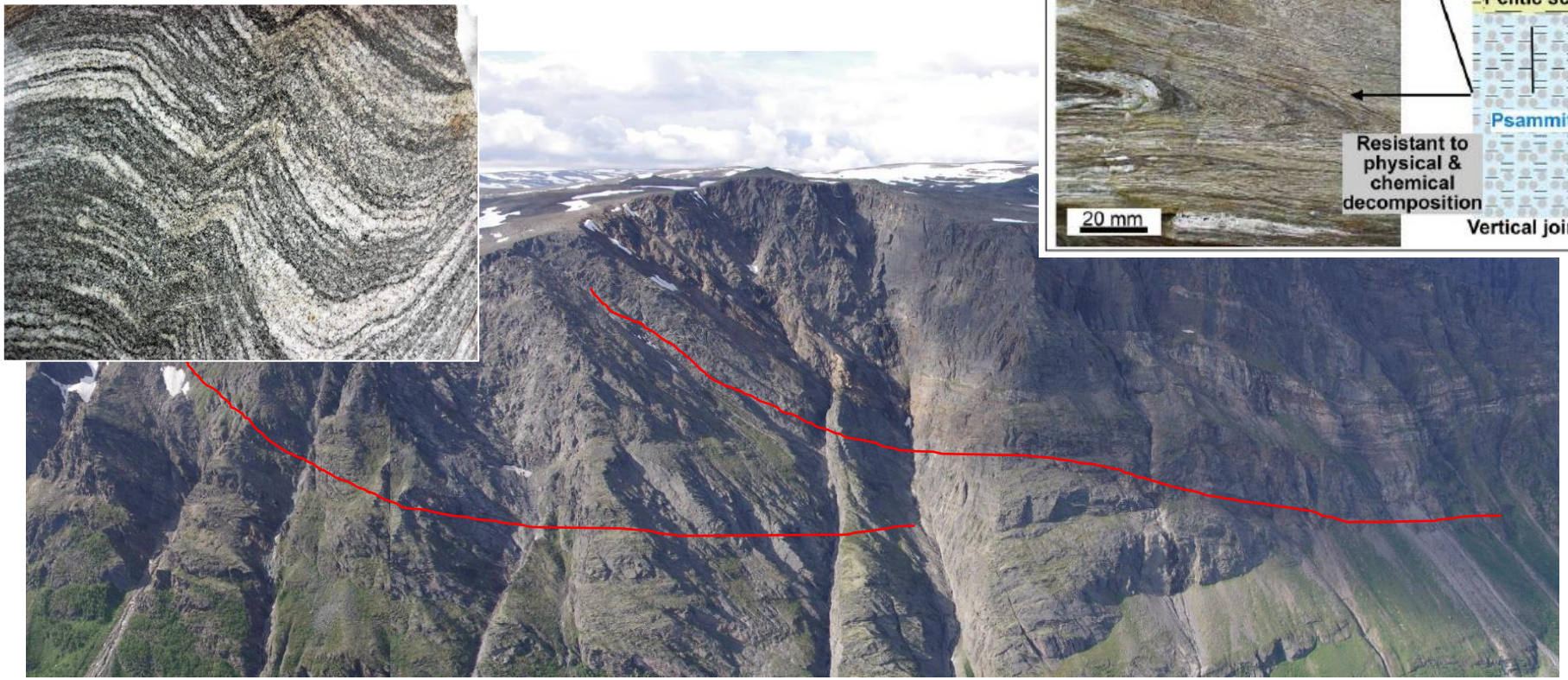


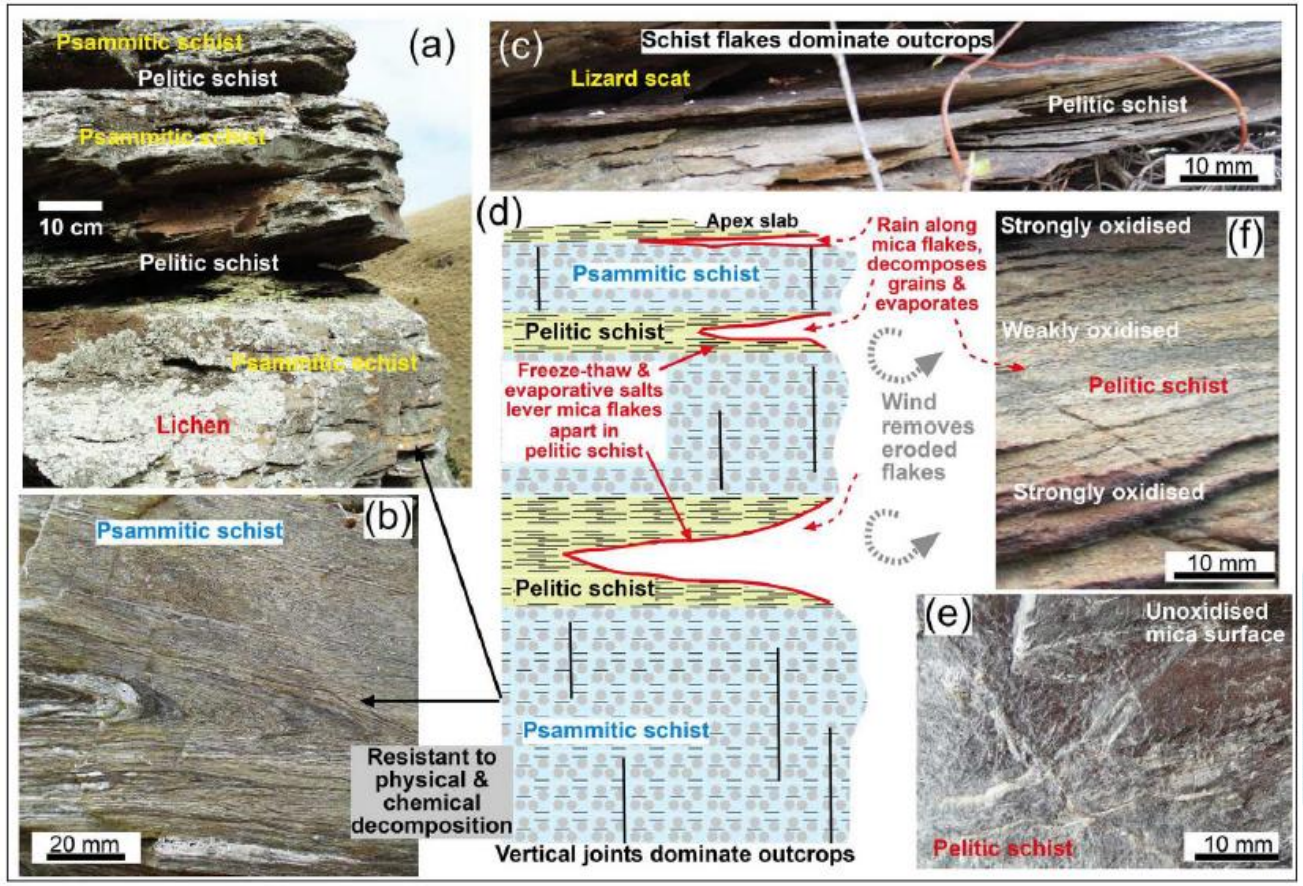
Guatemala, Geologypage.com

Spain, EGU Tectonics and structural geology blog

Macraes gold mine, Otago.ac.nz geology blog

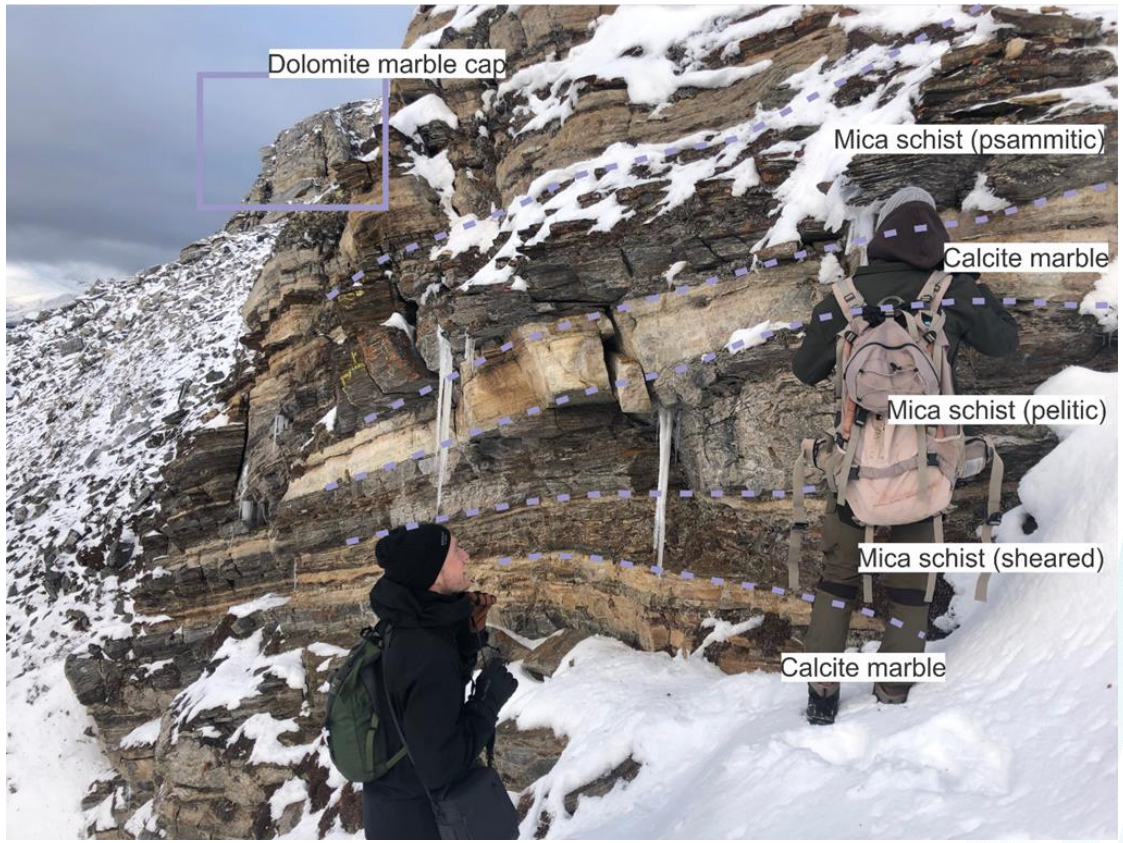
Thrust nappes, n Norway





Otago schist
Aitken et al. 2025

Punakaiki
DOC

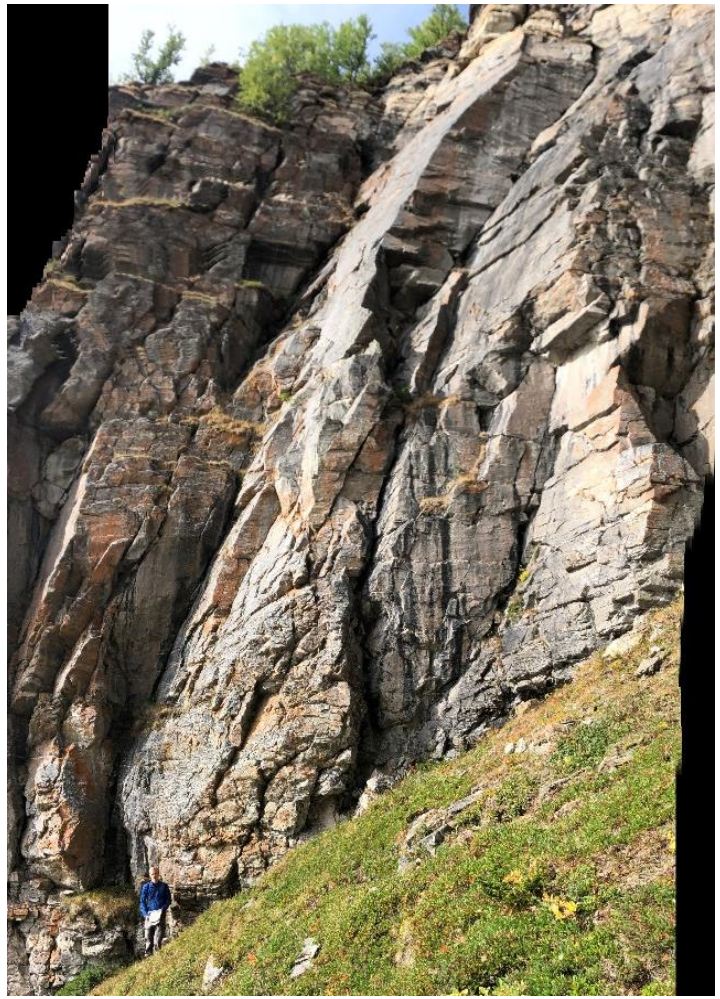


Jettan rockslide
n Norway

Discontinuities

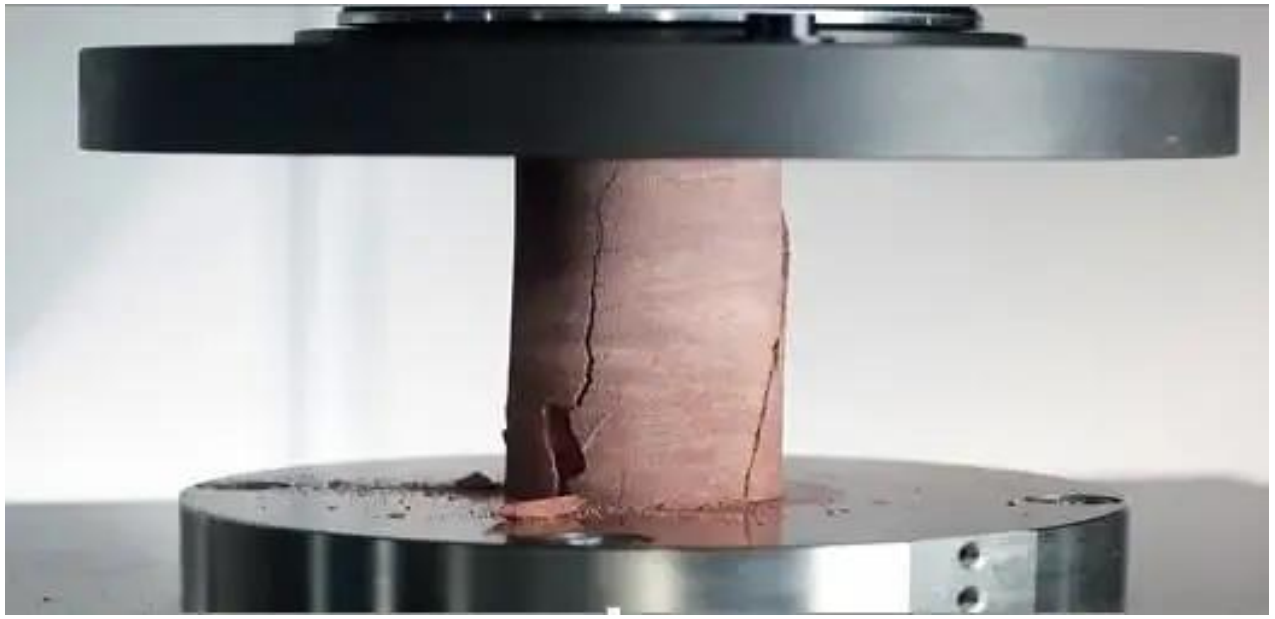
- …fractures, cracks, defects
- A separation in the rock with zero tensile strength
- No genetic connotation on defect type or origin

ISRM, 1978



N Norway

Intact rock



Theconstructor.org

	Granite	Basalt	Gneiss	Schist	Quart-zite	Marble	Lime-stone	Sand-stone	Shale
Av. C_o	181.7	214.1	174.4	57.8	288.8	120.5	120.9	90.1	103.0
Max. C_o	324.0	358.6	251.0	165.6	359.0	227.6	373.0	235.2	231.0
Min. C_o	48.8	104.8	84.5	8.0	214.9	62.0	35.3	10.0	34.3
Range	275.2	253.8	166.5	157.6	144.1	165.5	337.7	225.2	196.7
No. of samples	26	16	24	17	7	9	51	46	14

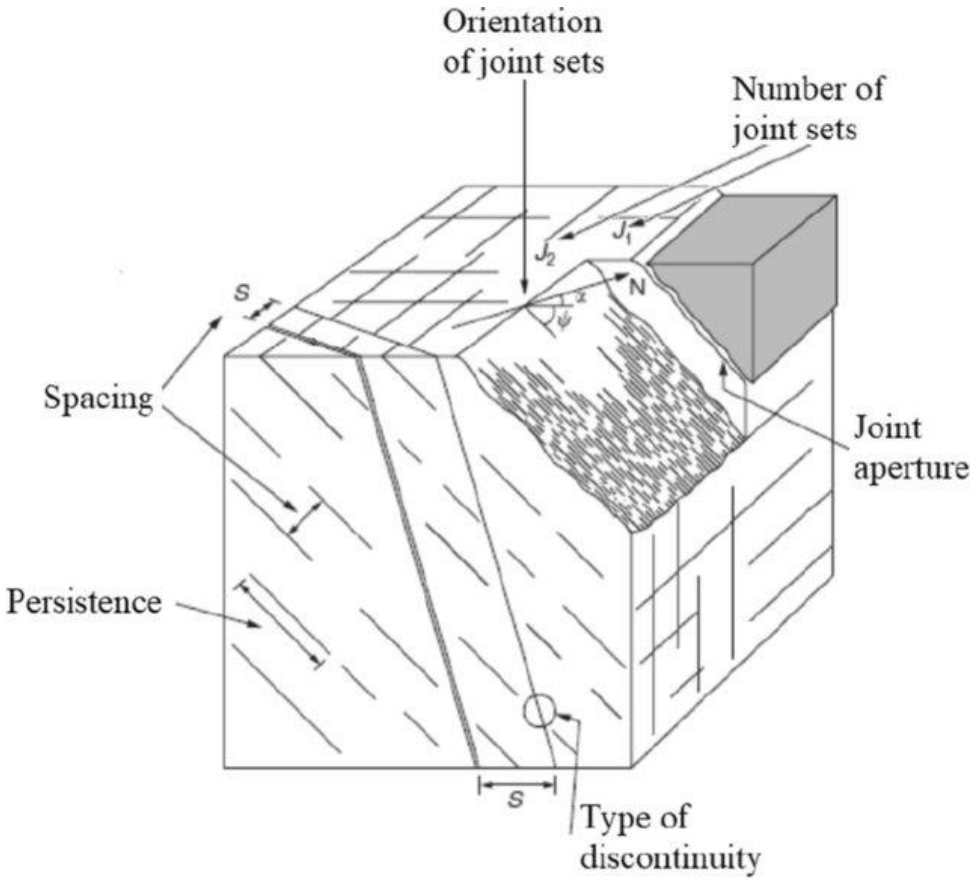
Table 1. Typical values of uniaxial strength (in MPa) for nine common rock types (after Johnson and Degraff, 1988).

Rock	Tensile Strength (MPa)	Compressive Strength (MPa)
Limestone	18.00 ± 0.62 (20)	41.45 ± 3.52 (4)
Sandstone	19.17 ± 0.21 (23)	77.59 ± 1.59 (5)
Sandstone	23.10 ± 0.48 (19)	80.83 ± 2.21 (10)
Sandstone	24.21 ± 0.83 (8)	90.48 ± 3.86 (4)
Mudstone	35.17 ± 3.17 (4)	50.07 ± 3.79 (4)
Limestone	36.28 ± 1.24 (24)	142.55 ± 6.14 (5)
Limestone	38.76 ± 2.69 (23)	142.97 ± 19.10 (8)
Ironstone	44.28 ± 4.48 (5)	190.69 ± 17.93 (4)
Sandstone	65.66 ± 0.83 (11)	167.66 ± 9.86 (5)

Table 2. Mean tensile strength and compressive strength for selected sedimentary rock types (after Johnson and Degraff, 1988).

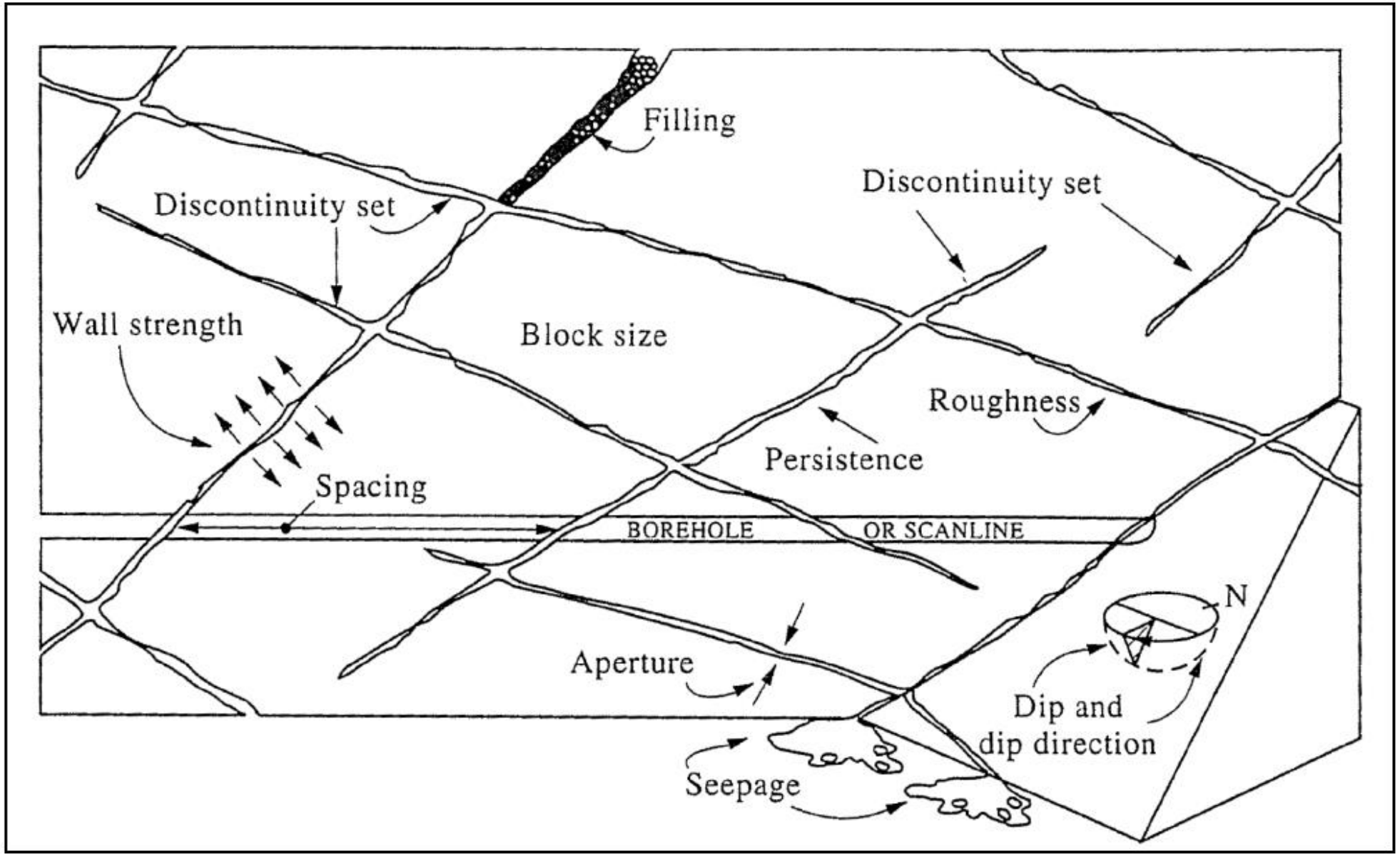
- Easy to determine provable strength in rock material

What is a rock mass?



Wylie, 1999

- In the majority of cases it is the discontinuities that influence the mechanical behaviour
- When undertaking engineering projects these need to be defined and characterised


Filling
Discontinuity set
Discontinuity set
Wall strength
Block size
Roughness
Persistence
Spacing
BOREHOLE
OR SCANLINE
N
Aperture
Dip and
dip direction
Seepage

NZ GEOTECHNICAL SOCIETY INC

ROCK > field guide sheet

FIELD DESCRIPTION OF ROCK

SEQUENCE OF TERMS – weathering – colour – fabric – rock name – strength – discontinuities – additional

SCALE OF ROCK MASS WEATHERING

Term	Grade	Abbreviation	Description
Unweathered (fresh rock)	I	UW	Rock mass shows no loss of strength, discolouration or other effects due to weathering. There may be slight discolouration on major rock mass defect surfaces or on clasts.
Slightly Weathered	II	SW	The rock mass is not significantly weaker than when fresh. Rock may be discoloured along defects, some of which may have been opened slightly.
Moderately Weathered	III	MW	The rock mass is significantly weaker than the fresh rock and part of the rock mass may have been changed to a soil. Rock material may be discoloured and defect and clast surfaces will have a greater discolouration, which also penetrates slightly into the rock material. Increase in density of defects due to physical disintegration.
Highly Weathered	IV	HW	Most of the original rock mass strength is lost. Material is discoloured and more than half the mass is changed to a soil by chemical decomposition or disintegration (increase in density of defects/fractures). Decomposition adjacent to defects and at the surface of clasts penetrates deeply into the rock material. Lithorelicts or corestones of unweathered or slightly weathered rock may be present.
Completely Weathered	V	CW	Original rock strength is lost and the rock mass changed to a soil either by decomposition (with some rock fabric preserved) or by physical disintegration.
Residual Soil	VI	RS	Rock is completely changed to a soil with the original fabric destroyed (pedological soil).

ROCK STRENGTH TERMS

Term	Field Identification of Specimen	Unconfined uniaxial compressive strength q_u (MPa)	Point load strength $I_{s(50)}$ (MPa)
Extremely strong	Can only be chipped with geological hammer	> 250	>10
Very strong	Requires many blows of geological hammer to break it	100 – 250	5 – 10
Strong	Requires more than one blow of geological hammer to fracture it	50 – 100	2 – 5
Moderately strong	Cannot be scraped or peeled with a pocket knife. Can be fractured with single firm blow of geological hammer	20 – 50	1 – 2
Weak	Can be peeled by a pocket knife with difficulty. Shallow indentations made by firm blow with point of geological hammer	5 – 20	<1
Very weak	Crumbles under firm blows with point of geological hammer. Can be peeled by a pocket knife	1 – 5	
Extremely weak (soil description required)	Indented by thumb nail or other lesser strength terms used for soils	<1	

Note: • No correlation is implied between q_u and $I_{s(50)}$

SPACING OF DEFECTS/ DISCONTINUITIES

Term	Spacing
Very widely spaced	>2 m
Widely spaced	600 mm – 2 m
Moderately widely spaced	200 mm – 600 mm
Closely spaced	60 mm – 200 mm
Very closely spaced	20 mm – 60 mm
Extremely closely spaced	<20 mm

APERTURE OF DISCONTINUITY SURFACES

Term	Aperture (mm)	Description
Tight	Nil	Closed
Very Narrow	> 0 – 2	
Narrow	2 – 6	
Moderately Narrow	6 – 20	Gapped
Moderately Wide	20 – 60	Open
Wide	60 – 200	
Very Wide	> 200	

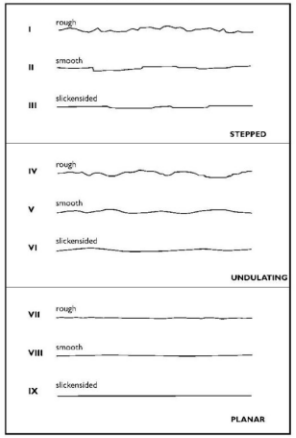
BEDDING THICKNESS TERMS

Term	Bed Thickness
Thinly laminated	< 2 mm
Laminated	2 mm - 6 mm
Very thin	6 mm - 20 mm
Thin	20 mm - 60 mm
Moderately thin	60 mm - 200 mm
Moderately thick	0.2 m - 0.6 m
Thick	0.6 m - 2 m
Very thick	> 2 m

BEDDING INCLINATION TERMS

Term	Inclination (from horizontal)
Sub-horizontal	0° – 5°
Gently inclined	6° – 15°
Moderately inclined	16° – 30°
Steeply inclined	31° – 60°
Very steeply inclined	61° – 80°
Sub-vertical	81° – 90°

ROUGHNESS AND APERTURE



compiled by KATE WILLIAMS design KARRYN MUSCHAMP

NZ GEOTECHNICAL SOCIETY INC

This field sheet has been taken from and should be used and read with reference to the document FIELD DESCRIPTION OF SOIL AND ROCK. Guideline For the Field Classification and Description of Soil and Rock for Engineering Purposes. NZ Geotechnical Society Inc, December 2005. **www.nzgeotechsoc.org.nz**

NZGS, 2005

Need to assess the condition of a rock mass both qualitatively and quantitively to:

- **Understand its quality** (Is it strong or weak? Stable or unstable?).
- **Plan construction** (What kind of support is needed, where to place construction?).
- **Predict behavior** (Will it collapse? Will it let water through?)

Classification systems

Classification systems assign a **score** or **rating** to the rock mass based on its features. The higher the score, the better the quality of the rock mass. These systems look at things like:

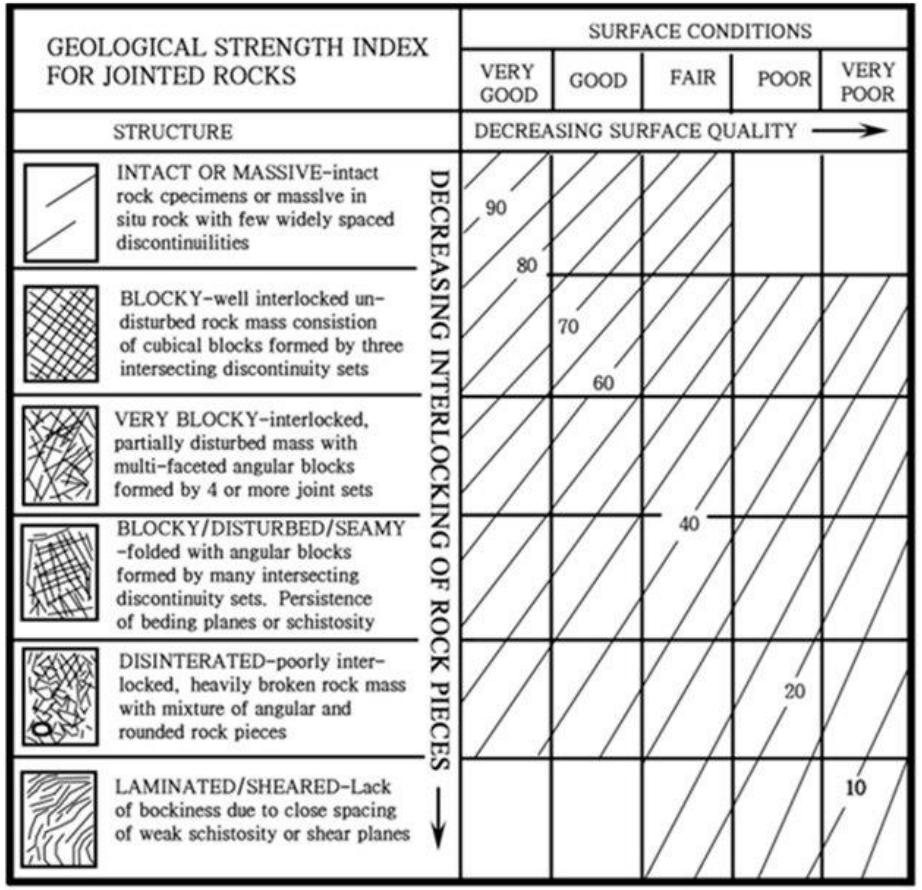
- **Strength of the intact rock** (How hard is the rock itself?).
- **Spacing of joints** (Are the discontinuities close together or far apart?).
- **Condition of joints** (Are they smooth, rough, or filled with weak material?).
- **Groundwater** (Is the rock mass dry or full of water?).

	Type of Rockmass classification														
Parameters used ▼	RQD	RSR	RMR	RMRB	Q	Qn	MRMR	RMS	MBR	SRMR	SMR	GSI	RCR	RMi	Total
Block size	×	×	×	×	×	×	×	×	√	×	×	×	×	√	2
Joint orientation	×	√	√	×	×	×	×	×	√	×	×	×	×	√	4
No. of joint sets	×	×	×	×	√	√	×	√	×	×	×	×	√	√	5
Joint Length	×	×	×	×	×	×	×	×	×	×	×	×	×	√	1
Joint Spacing	√	√	√	√	√	√	√	√	√	√	√	√	√	√	14
Joint Strength	×	√	√	√	√	√	√	√	√	√	√	√	√	√	13
Rock type	×	√	×	×	×	×	×	×	×	×	×	×	×	×	1
State of Stress	×	×	×	×	√	×	√	×	√	×	×	×	×	×	3
Ground water condition	×	√	√	√	√	√	√	√	√	√	√	×	√	×	11
Strength of intact rock	×	×	√	√	×	√	√	√	√	√	√	×	√	√	10
Total No. of variables used	1	5	5	4	4	5	5	5	7	4	4	2	5	7	

Geotechnicaldesigns.com.au

GSI (Geological Strength Index)

- A simple system that uses visual observations of the rock mass.
- Rates the rock mass based on how broken it looks and the condition of the joints.
- Useful for quick assessments.



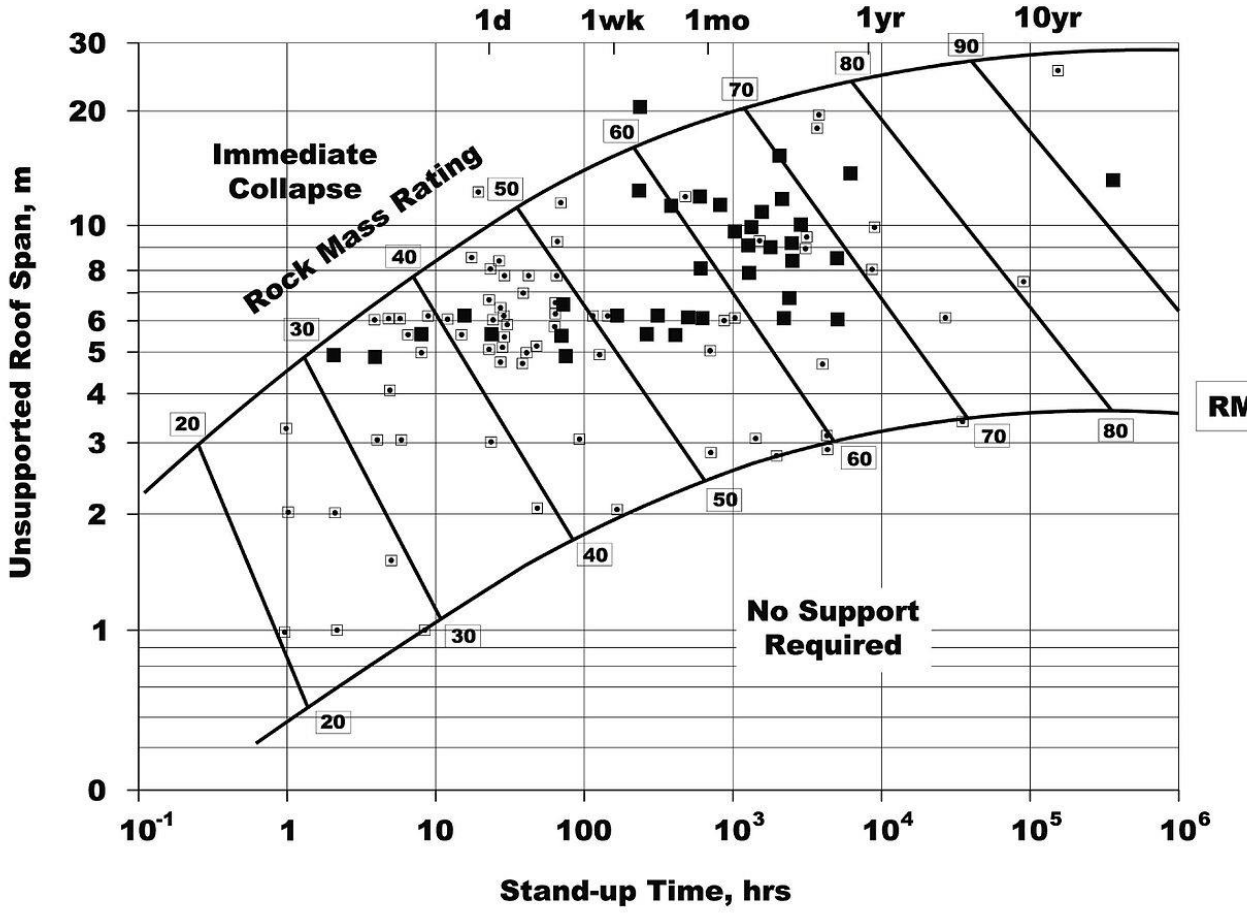
Hoek 1994

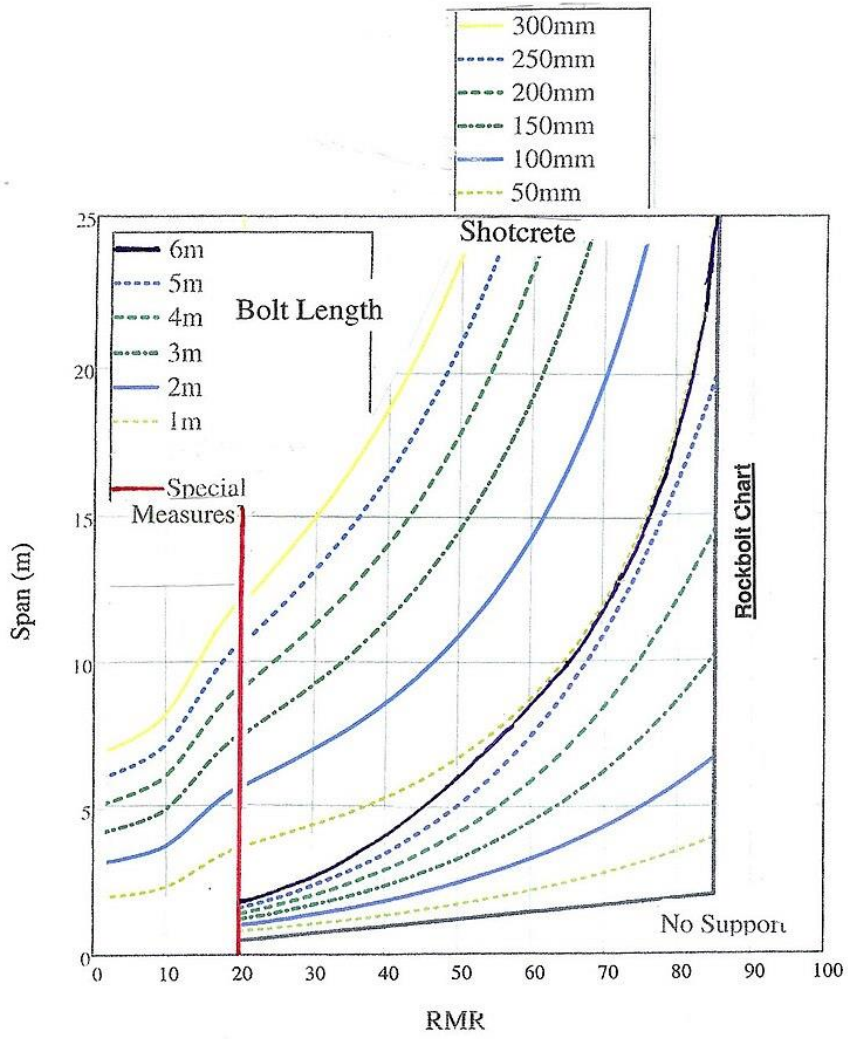
RMR (Rock Mass Rating) System

- Assigns a score based on factors like rock strength, joint spacing, and groundwater.
- Categorizes the rock mass into classes from very good to very poor- higher scores mean better rock quality.
- Used to decide how much support (like bolts or concrete) is needed for tunnels or slopes.

Bieniawski 1972

Parameter			Ranges of values						
1	Strength of intact rock material	Point-load strength index (MPa)	>10	4 - 10	2 - 4	1 - 2	For this low range, uniaxial compressive test is preferred		
		Uniaxial compressive strength (MPa)	>250	100 - 250	50 - 100	25 - 50	5 - 25	1 - 5	<1
		Rating	15	12	7	4	2	1	0
2	Drill core quality RQD (%)		90 - 100	75 - 90	50 - 75	25 - 50	<25		
		Rating	20	17	13	8	3		
3	Spacing of discontinuities		>2m	0.6 - 2m	200 - 600mm	60 - 200mm	<60mm		
		Rating	20	15	10	8	5		
4	Condition of discontinuities		Very rough surfaces Not continuous No separation Unweathered wall rock	Slightly rough surfaces Separation <1mm Slightly weathered wall rock	Slightly rough surfaces Separation <1mm Highly weathered wall rock	Slickensided surfaces or Gouge <5mm thick or Separation 1 - 5mm Continuous	Soft gouge >5mm thick or Separation >5mm Continuous		
		Rating	30	25	20	10	0		
5	Groundwater	Inflow per 10m tunnel length (l/min)	None	<10	10 - 25	25 - 125	>125		
		ratio (joint water pressure)/(major principal stress)	0	<0.1	0.1 - 0.2	0.2 - 0.5	>0.5		
		General conditions	Completely dry	Damp	Wet	Dripping	Flowing		
		Rating	15	10	7	4	0		


1d
1wk
1mo
1yr
10yr
Immediate Collapse
Rock Mass Rating
No Support Required
Unsupported Roof Span, m
Stand-up Time, hrs
RM


300mm
250mm
200mm
150mm
100mm
50mm
6m
5m
4m
3m
2m
1m
Bolt Length
Shotcrete
Special Measures
Rockbolt Chart
No Support
Span (m)
RMR

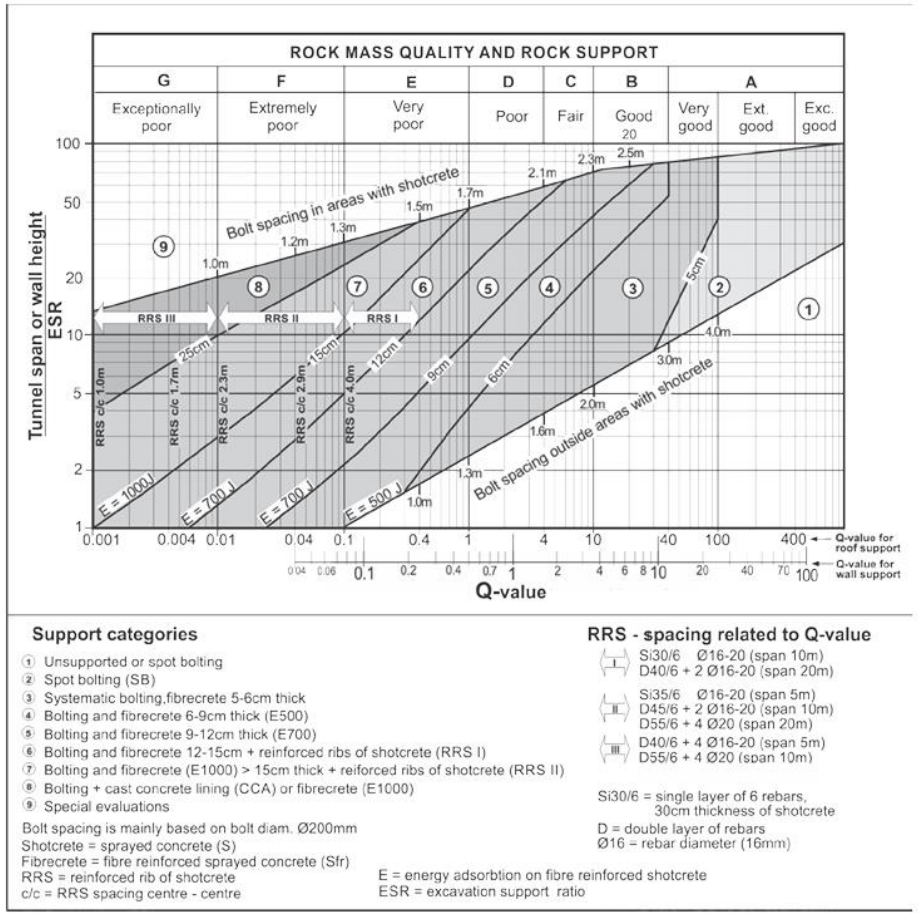
Parameter	L1	L2	L3	L4	L5
Rock type	Epidiorite	Tilwara quartzite	Phyllite	Rudraprayag quartzite	Rudraprayag metavolcanics
Mean UCS	58 MPa	40 MPa	28 MPa	54 MPa	123 MPa
RQD (calculated from JV)*	85 %	65%	49%	80%	92%
Joint spacing	20 cm – 60 cm	20 cm – 6 cm	< 60 mm	20 cm – 6 cm	> 2 m
Joint roughness	Rough	Rough	Smooth	Slightly rough	Rough
Joint separation	0.1 - 1 mm	1 - 5 mm	1 - 5 mm	0.1 - 1 mm	1 - 5 mm
Joint persistence	3 - 10m	1 - 3 m	10 - 20 m	1 - 3 m	3 - 10m
Joint infilling	None	Soft filling >5 mm	Hardfilling >5 mm	None	None
Weathering	Slightly weathered	Moderately weathered	Slightly weathered	Slightly weathered	Unweathered
Ground water condition	Dry	Dry	Dry	Dry	Dry

Road cut design, Himalaya
Umrao, 2011

Q-System

- Focuses on joint properties and how they affect stability.
- Uses a formula to calculate a "Q-value"
- Commonly used in tunneling projects.

Barton et al. 1974

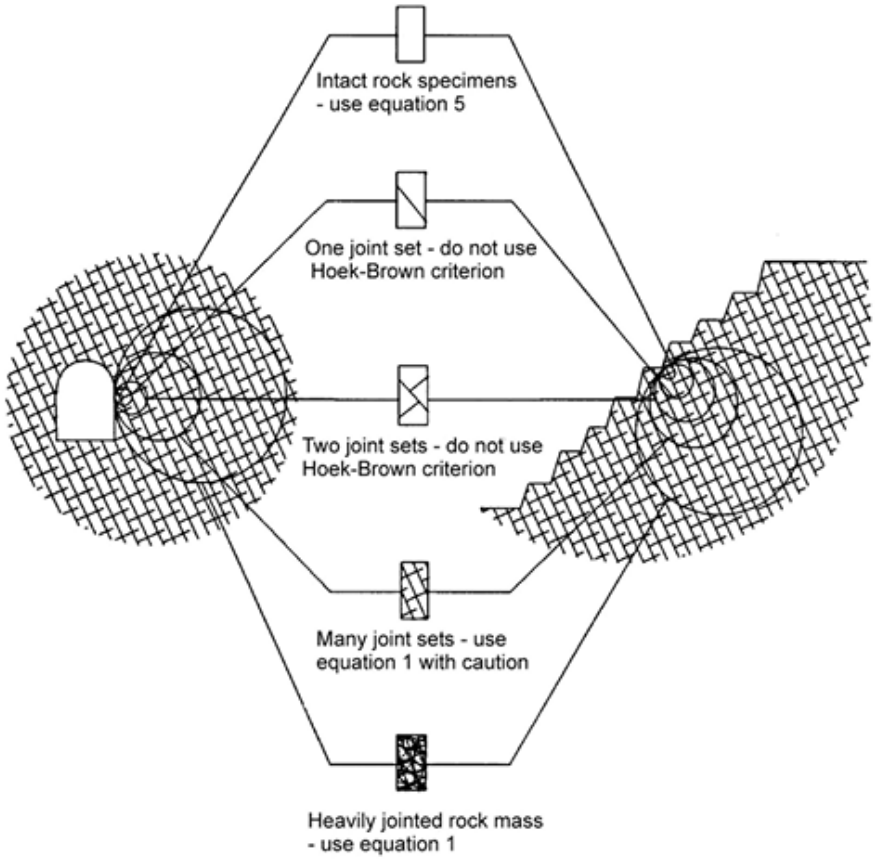


Application

- Catalogue of terrain engineering geology units
- Input to geomechanical models
- The determine integrity of current designs
- To communicate rock properties to engineers for design

Limitations

- Simplified Assumptions
- Site-Specific Variability
- Subjectivity
- Static Representation

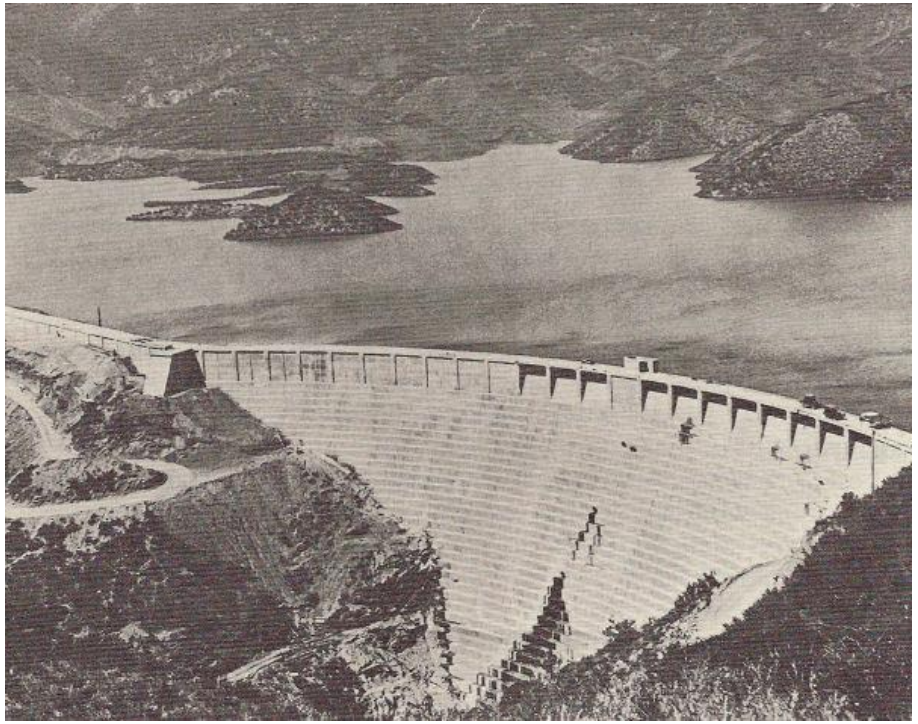


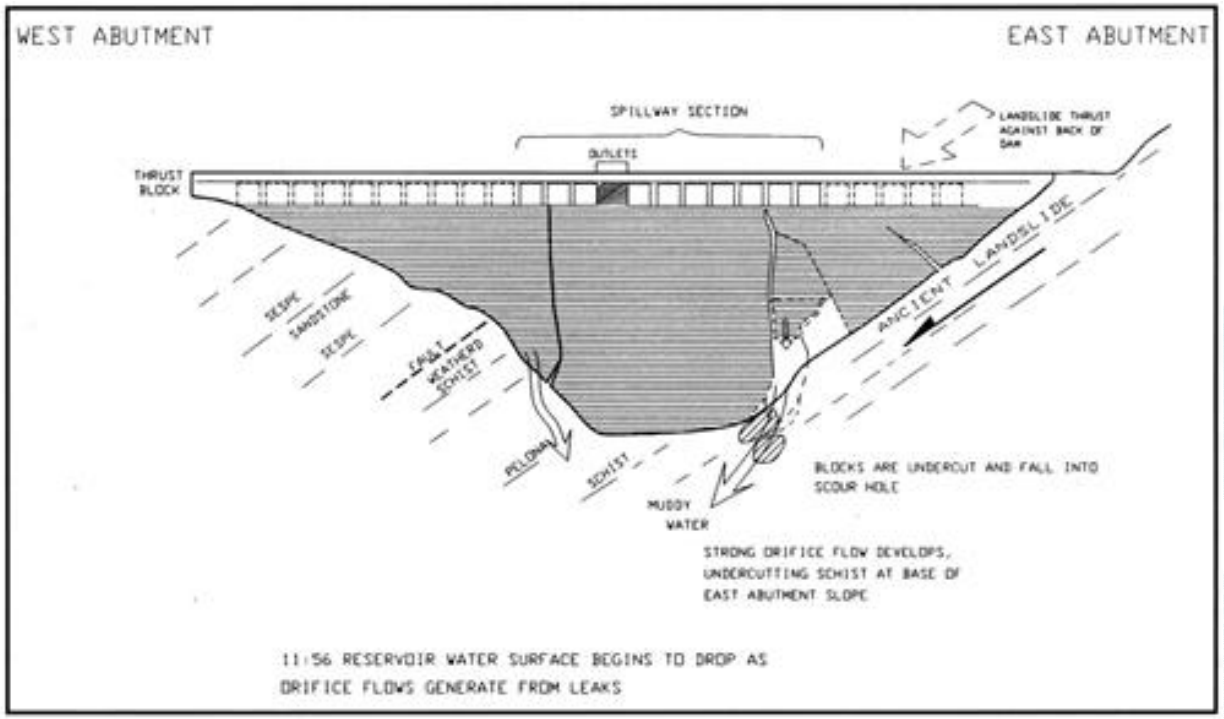
Assessing rock mass strength

- ‘Assigning numbers to geology requires a delicate balance between the commonly held opinion that geology cannot be quantified and the overoptimistic view that every physical quantity can be described in precise mathematical terms. In reality, many geological characteristics cannot be quantified precisely and intelligent guesses based upon experience and logical arguments are the best that can be hoped for.’
  - Evert Hoek, 2nd Glossop lecture, 1999

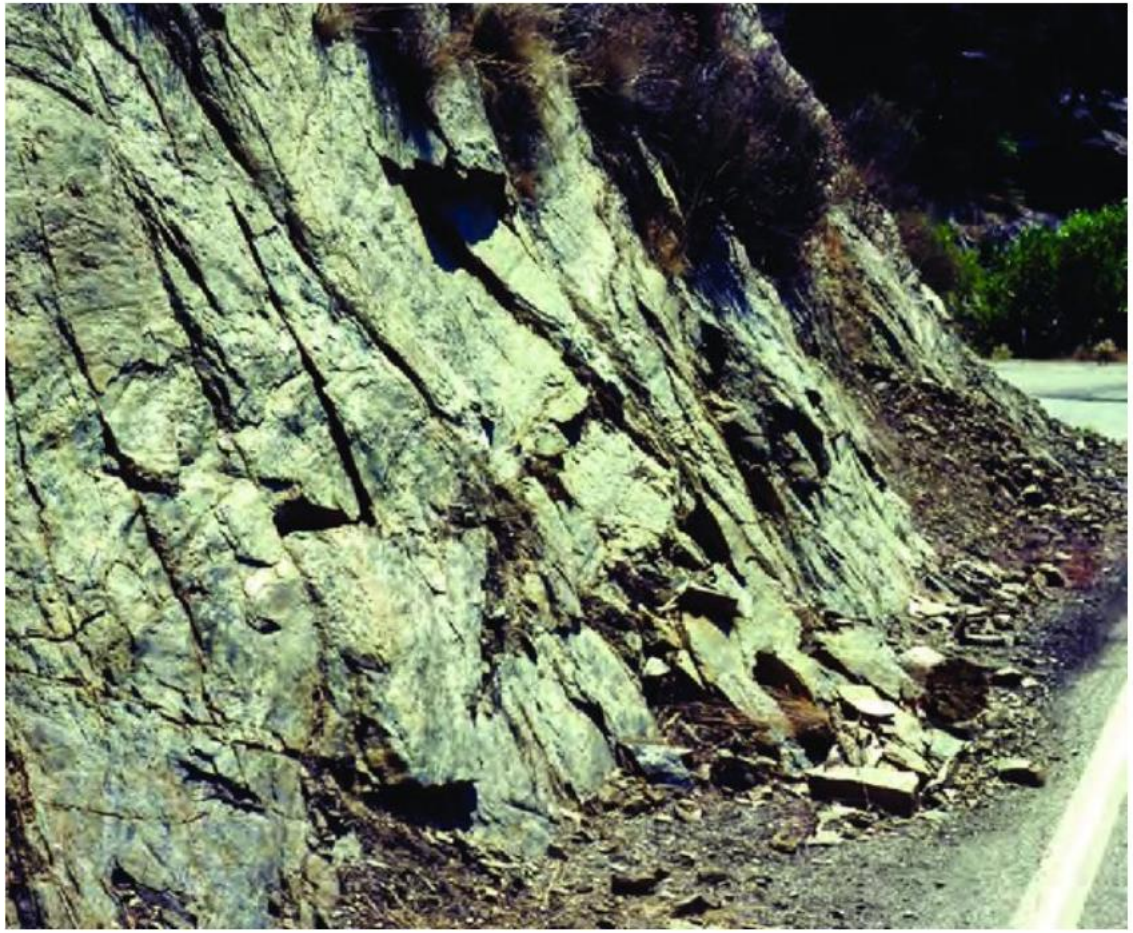
Case study: St Francis Dam collapse

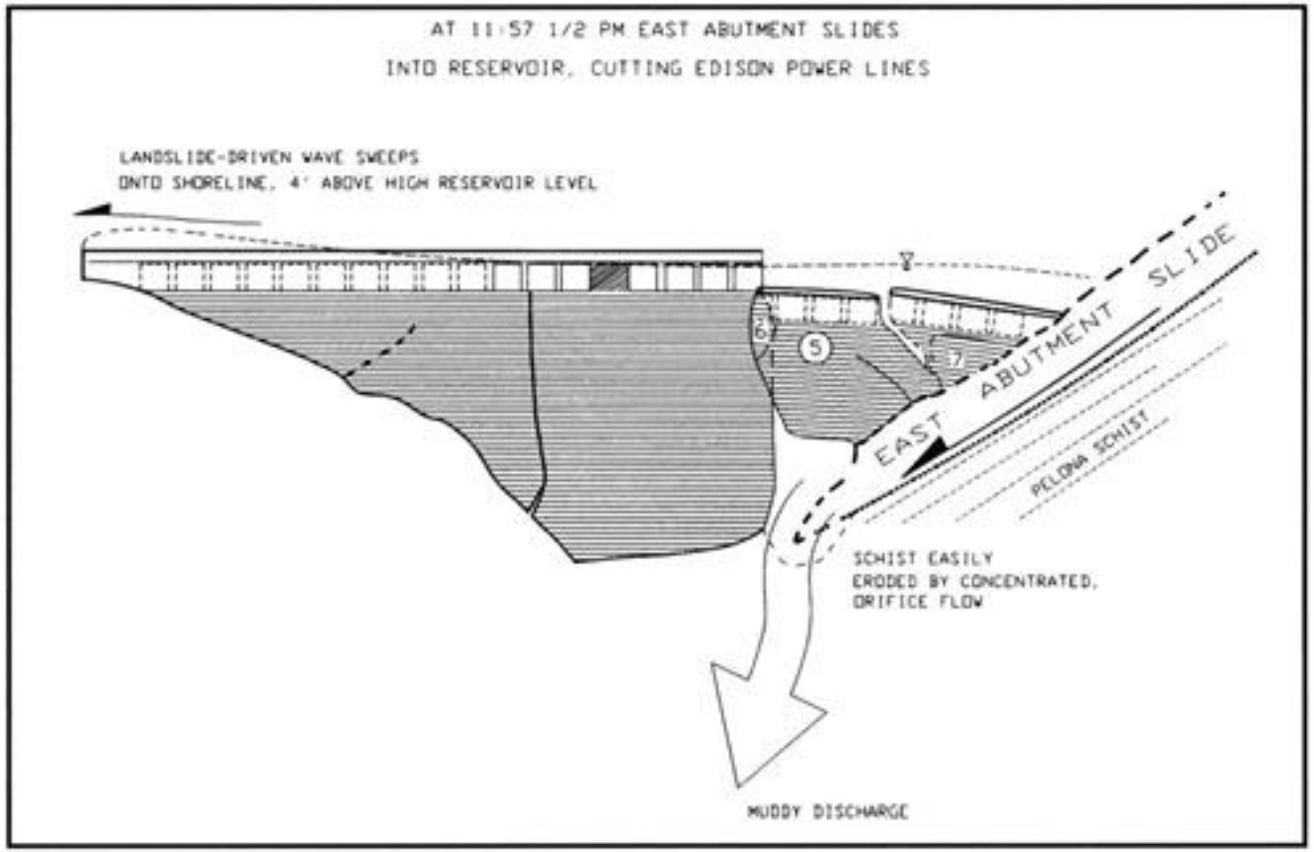
- Pivotal points in the history of engineering geology





A





- "It is desirable to have a careful geological examination of the foundation conditions, ideally one in the form of an investigation and report by an expert practical geologist."
- Such a study at the St. Francis site would most likely have uncovered the vulnerability of the sandstone and mica schist formations to seepage, as well as the paleo-landslide flanking the proposed dam's east abutment (which several geologists readily observed at the site after the breach)

Hool and Kinne, 1923

Do not edit
How to change the design

Please fill in the survey

The Slido app must be installed on every computer you're presenting from

slido